

Inadvertent Screw Stripping During Ankle Fracture Fixation in Elderly Bone

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Abstract

Poor screw purchase because of osteoporosis presents difficulties in ankle fracture fixation. The aim of our study was to determine if cortical thickness, unicortical versus bicortical purchase, and bone mineral density are predictors of inadvertent screw stripping and overtightening. Ten paired cadaver ankles (average donor age, 81.7 years; range, 50-97 years) were used for the study. Computed tomography scanning with phantoms of known density was used to determine the bone density along the distal fibula. A standard small-fragment, 7-hole, one-third tubular plate was applied to the lateral surface of the fibula, with 3 proximal bicortical cortical screws and 2 distal unicortical cancellous screws. A posterior plate, in which all 5 screws were cortical and achieved bicortical purchase, was subsequently applied to the same bones and positioned so that the screw holes did not overlap. A torque sensor was used to measure the torque of each screw during insertion (T_i) and then stripping (T_s). The effect of bone density, screw location, cortical thickness, and unicortical versus bicortical purchase on T_i and T_s was checked for significance ($P < .05$) using a general linearized latent and mixed model. We found that 9% of the screws were inadvertently stripped and 12% were overtightened. Despite 21% of the screws being stripped or being at risk for stripping, we found no significant predictors to warn of impending screw stripping. Additional work is needed to identify clinically useful predictors of screw stripping.

Keywords

insertion torque, stripping torque, bone density, inadvertent stripping, ankle fracture

Introduction

As a screw is inserted into bone, the screw head compresses the plate against the bone with a force proportional to the torque applied to the screw.¹ If the screw is tightened beyond the ultimate strength of the bone-screw interface, the screw threads will lose purchase in the bone and the screw will spin with little resistance. Although pullout strength is related to the depth of the screw thread² and quality of the bone,³ stripping the screw reduces the pullout strength of the screw by more than 80%.⁴ Inserting screws beyond 70% of the maximum torque compromises pullout strength,⁵ yet screws are typically inserted to 86% of maximum torque clinically.⁶ As density decreases, screws are at increased risk of stripping and pullout. For these reasons, osteoporosis poses challenges in fracture treatment.

Screw stripping poses concerns for fracture fixation, and the stripped screw may not be recognized by the surgeon. According to 1 study, stripping of at least 1 screw during internal fixation of displaced lateral malleolar fractures occurs in up to 88% of patients more than 50 years old.⁷ The prevalence of inadvertent screw stripping during plate fixation and the clinical consequences of such stripping are unknown. The aim of our study was to determine if cortical thickness, unicortical versus

bicortical purchase, and bone mineral density are predictors of inadvertent screw stripping and overtightening during ankle fracture fixation in the elderly.

Materials and Methods

Specimens and Testing Procedures

Ten pairs of fresh-frozen cadaver legs (mean donor age, 81.7 years; range, 50-97 years) were obtained from the State

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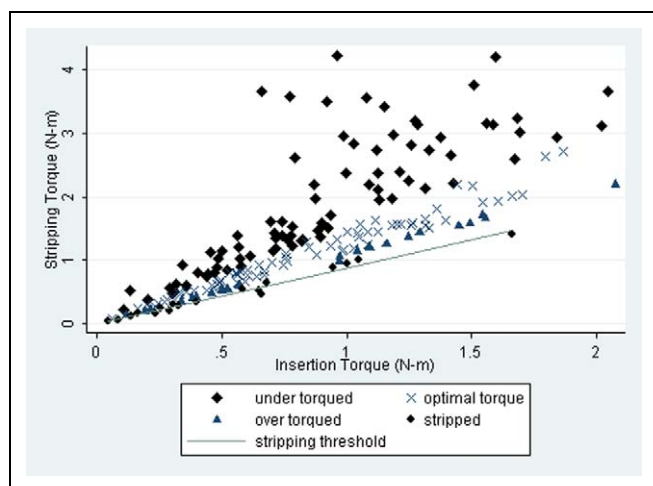


Figure 1. Stripping versus insertion torques.

Anatomy Board. They were kept frozen (-10°C) until needed for the study, at which time they were thawed at room temperature.

To determine bone density along the distal fibula, we used a multislice computed tomography (CT) scanner (Toshiba Aquilion 16, Toshiba America Medical Systems, Tustin, California), with a slice thickness of 2 mm. A phantom slab (Computerized Imaging Referencing Systems, Norfolk, VA) containing 6 hydroxyapatite rods of known densities (50, 200, 500, 1000, 1250, and 1500 mg/mL) was placed alongside the fibula during CT scanning to establish a calibration curve to convert the CT density in Hounsfield units to actual bone density in milligrams per milliliter.

The “ellipse” function on the CT workstation software (Vitrea 2, Vital Images, Minnetonka, Minnesota) was used to select the circular cross-section of each of the 6 rods in the phantom slab and to determine their density in Hounsfield units. This procedure was repeated every 10 mm, and the values for at least 10 measurements were averaged. The known density for each rod (in milligrams per milliliter) was then plotted against the average density (in Hounsfield units) to construct a calibration curve, with the slope being the conversion factor.

Using the “freehand selection” tool on the CT workstation software, the density and area of the fibular cross-section were measured in Hounsfield units and square millimeters, respectively, for each CT slice, starting from the distal tip of the fibula. The distance of each cross-section from the distal tip of the fibula was easily determined using the fact that each CT slice was 2 mm thick. The actual bone density of each fibular cross-section was then determined from the calibration curve to convert Hounsfield units to milligrams per milliliter. To construct a curve for the variation of bone density along the distal fibula, each value was plotted against its respective distance from the tip of the fibula. This procedure was repeated for each of the 20 fibulae. Bone mineral density increased significantly from the distal to the proximal fibula (Figure 1), varying from 186 distally to 1138 mg/mL proximally.

Each fibula was exposed via a lateral approach. Seven-hole, stainless-steel, one-third tubular plates and 3.5-mm fully

threaded, self-tapping cortical screws or 4.0-mm cancellous screws were used (Synthes, Paoli, Pennsylvania). The plates were precontoured to fit the distal fibula. A 2.5-mm-diameter drill was used to drill all screw holes. Then the plates were applied with 3 proximal screws and 2 distal screws. For the lateral plate construct, the proximal 3 cortical screws achieved bicortical bony purchase and the distal 2 screws were cancellous and unicortical. After determining insertion and stripping torques of the screws, the construct was removed and a posterior plate was applied. Because of the normal distal fibular anatomy, the posterior plate was slightly offset from the tip of the fibula to avoid the peroneal groove. No posteroanterior screw path coincided with a previous lateral-medial screw path (Figure 1). For the posterior plate construct, all screws were cortical in design and achieved bicortical bone purchase.

For descriptive purposes, the screws were numbered sequentially (1 to 5) from proximal to distal. A trauma-trained orthopedic surgeon manually inserted each screw and tightened it “optimally” using only thumb and finger pressure on the screwdriver. The screwdriver was linked to a torque sensor (TQ 103-50, Omega Engineering, Stamford, Connecticut) that allowed real-time determination of the applied torque with an accuracy of 0.02 Nm. After determination of this optimal insertion torque (T_i), the screw was tightened further until it failed by stripping. The torque at stripping (T_s) was also recorded (Table 1). Starting with the most proximal screw, each screw was inserted and then stripped before inserting and stripping the next screw. If T_s was less than T_i , then the screw had been inadvertently stripped during insertion. In such cases, T_i was the stripping torque. In all cases, the operator was blinded to the torque values to prevent bias secondary to the visual feedback from the torque sensor. Three screws could not be stripped because the heads were sheared off in the attempt to strip. All 3 screws were in proximal locations: 2 in the most proximal position (position 1) and 1 in position 2. These 3 screws were excluded from analysis.

We defined a new variable, percent-torque, as the T_i value divided by the T_s value. Based on previous reports, we chose to stratify our data into four groups: 0 = under-torqued (0% to 64%); 1 = optimal (65% to 89%); 2 = over-torqued (90% to 99%); and 3 = stripped ($\geq 100\%$).

After removal of all the hardware, each fibula was disarticulated and examined. For both constructs, the distance of the center of each screw hole from the distal tip of the fibula was measured using a digital caliper (Mitutoyo, Aurora, Illinois). With the distal tip of the fibula as the origin, this distance was used to obtain the bone density at each screw hole from the CT slice corresponding to that location (ie, distance from the origin). If a screw hole was located “between” CT slices because its distance from the fibular tip was an odd value, the average of the 2 adjacent slices was used. This procedure was repeated for each of the 20 fibulae.

Statistical Analysis

The effect of screw location (1 to 5), bicortical versus unicortical purchase, cortical thickness, and bone density on T_i and T_s

Table 1. Mean (SD) Cortical Thickness Engaged by Screws

Screw Hole	Lateral Plate				Posterior Plate			
	Cortical Thickness (mm)	Density (mg/ml)	Insertion Torque (Nm)	Stripping Torque (Nm)	Cortical Thickness (mm)	Density (mg/ml)	Insertion Torque (Nm)	Stripping Torque (Nm)
1	4.8 (1.2)	889 (139)	1.0 (0.4)	2.2 (12.5)	5.5 (1.4)	901 (135)	1.0 (0.2)	2.3 (0.8)
2	4.6 (1.0)	810 (120)	1.1 (0.5)	1.8 (0.9)	4.9 (1.4)	845 (133)	1.2 (0.6)	1.7 (0.9)
3	4.2 (1.2)	709 (109)	0.9 (0.4)	1.1 (0.4)	4.3 (1.0)	765 (111)	1.0 (0.4)	1.4 (0.6)
4	1.4 (0.3) ^a	318 (74)	0.3 (0.2)	0.4 (0.4)	3.3 (0.8)	345 (76)	0.7 (0.3)	1.0 (0.6)
5	1.2 (0.2) ^a	311 (53)	0.4 (0.2)	0.5 (0.4)	2.7 (0.5)	309 (65)	0.7 (0.3)	1.0 (0.4)

^a Unicortical screw engagement.

were checked for significance ($P < .05$) using a general linearized latent and mixed model (Stata 10, StataCorp LP, College Station, Texas). We also checked for predictors of percent-torque group based on screw location (1 to 5), bicortical versus unicortical purchase, cortical thickness, and bone density using multinomial logistic regression.

Results

During insertion of the 200 screws, 18 screws were inadvertently stripped. None of the most proximal screws (position 1) was inadvertently stripped. Progressively more screws were inadvertently stripped more distally in the fibula. There were 3, 4, 5, and 6 screws inadvertently stripped at positions 2, 3, 4, and 5, respectively (proximal to distal). There were no significant associations of screw location, unicortical versus bicortical purchase, density squared, or thickness on the risk of inadvertent stripping, suggesting that none of these covariates was a good predictor of inadvertent stripping. Neither were any of the covariates a significant predictor of the percent-torque group assignment.

T_i varied from 0.04 to 2.08 Nm (Table 1). There was a significant but weak correlation between insertion torque ($r^2 = .46$) and density squared. Cortical thickness and density squared were significantly associated with insertion torques.

T_s varied from 0.66 to 4.23 Nm, generally decreasing from proximal to distal screw positions. There was a significant but similarly weak correlation ($r^2 = .55$) between stripping torque and density squared. Density squared and cortical thickness were significantly associated with stripping torque.

On average, insertion torque was 71% of the measured stripping torques. Of the 200 screws inserted, 82 were in the under-torqued group (0% to 64%), 76 were in the optimal-torque group (65% to 89%), 24 were in the over-torqued group (90% to 99%), and 18 were in the inadvertently stripped group ($\geq 100\%$). Of the 82 screws in the under-torqued group, 36 had stripping torques above 2 Nm, which was the highest insertion torque deemed clinically relevant in the current study.

Discussion

In the current study, we sought to determine risk factors for inadvertent screw stripping and overtightening during fixation

of ankle fractures in elderly bones. Approximately 9% of our screws were inadvertently stripped; a result consistent with the literature.⁶ Another 12% of the screws were overtightened or within 10% torque of being stripped. We found no significant predictors of inadvertent stripping or overtightening. Although the risk of inadvertent stripping increased the more distal the screw, this trend was not significant and was not associated with cortical thickness or bone density. The risk of inadvertent stripping was also greater in the lesser dense bone but not significantly so.

We labeled screws as optimally tightened if the insertion torque was between 65% and 89% stripping torque. Cleek et al⁵ suggested that torsioning screws to 70% of their maximum torque results in peak pullout strength. Cordey et al⁶ reported that clinicians typically tighten screws to 86% of maximum. Both of the definitions of "optimal" are subjective. The former assumes that achieving maximum pullout strength is an indicator of successful fracture fixation. We know of no literature to support the conjecture that maximizing pullout strength results in fewer nonunions or loss of fracture fixation. The latter relies on a surgeon's experience at inserting screws to remain below the stripping torque, but again, it is unknown if achieving an average 86% peak torque results in fewer clinical complications associated with fracture fixation. In short, neither value takes into account the clinical demands on the screw. A clinician may torque a screw to 70% of the maximum but may still not have enough purchase for the screw to function as intended. In contrast, a screw torsioned to less than 70% may appear under-torqued but may provide sufficient purchase. Screws in the current study were inserted to 71% of their stripping torque, but values ranged from 18% to $\geq 100\%$. The low percentage insertion-to-stripping torque values were for screws that were deemed sufficiently tightened ($n = 36$ screws) so as not to need further torquing to levels that approached failure torque; however, without knowing the resulting pullout strength of the screws and the site-specific bone quality (thickness and density), and the effect on fracture fixation and healing, it is difficult to know the clinical significance of the value.

There are limited reports about the optimal insertion torque of a screw with respect to bone density in the appendicular skeleton,^{3,6,8} but we found no such reports on the distal fibula. We investigated the effect of bone density on the insertion and stripping torques during screw insertion in the distal fibula.

Previous reports have tried to determine optimal insertion torques for screws in the ovine tibia (2 Nm⁶) and diaphyseal human tibia (2.1 Nm⁶ to 3 Nm⁶). In diaphyseal human tibias, an average stripping torque of 3.3 Nm has been reported,⁶ although the effect of bone density was not explored. A more recent study found significant positive correlations between pull-out strengths of 3.5-mm screws and the bone density and cortical thickness in human diaphyseal femurs.⁹ In the current study, the orthopedic surgeon inserting screws deemed it unnecessary to tighten screws beyond 2 Nm, based on clinical judgment. In some cases (36 screws), this decision classified screws as being under-torqued because the insertion value was below 65% of the stripping torque value, but likely to be clinically sufficient.

Although it is reported that higher insertion torques are associated with higher bone density in the femur,⁸ our study is the first, to our knowledge, to quantify these relationships in the distal fibula as the torque required to strip a screw being proportional to the pullout strength. Although it is academically interesting to know the relationship between torque and pullout strength, what is clinically more important is establishing a range of torque values that provide the bounds of clinically sufficient purchase.

One of the limitations of our study is that cadaver bone may not be mechanically equivalent to living bone. Indeed, 1 study found insertion torques of spinal pedicle screws to be significantly higher in vivo than in vitro.¹⁰ Possible explanations for this discrepancy include postmortem changes, such as the lack of intraosseous pressure,¹¹ saponification of fatty acids from necrosing marrow fat cells,¹² and alteration of collagen fibers and water content by freeze-thaw cycles.¹³ However, although these factors would affect the absolute values of T_i and T_{ss}, comparisons and trends would still be expected to be valid. Only 1 surgeon performed the screw insertion during this study. The surgeon is a trauma-trained practicing orthopedic surgeon who cares for elderly patients with ankle fractures. The skill level of the surgeon may play a role in the insertion of the screws, and that point was not investigated in this study. Another limitation of the study is that, in an attempt to more closely replicate the clinical situation, the inserter was not blinded to the screw position. Clearly, the knowledge of the screw position and the visual feedback of the screw inserting into the bone also play a role in the torque applied by the inserting surgeon. These effects were not investigated in this study.

In conclusion, we have shown a weak positive correlation between bone density squared and insertional and stripping torque of screws in the distal fibula. We found no significant predictors of inadvertent screw stripping or overtightening. Additional work will be required to determine a way to predict the optimal insertion of bone screws.

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